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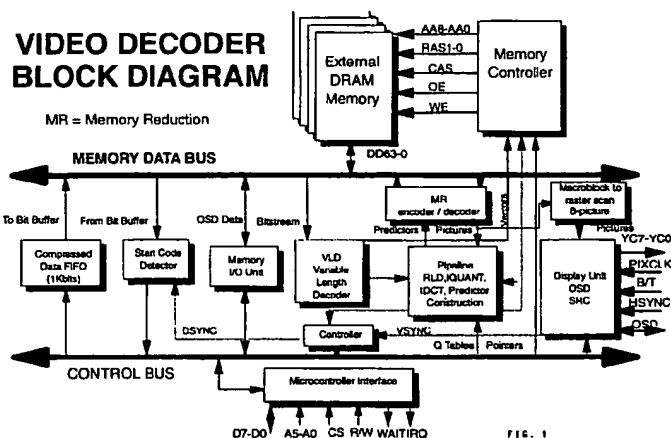
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(54) **MPEG-2 decoding with a reduced RAM requisite by ADPCM recompression before storing MPEG-2 decompressed data optionally after a subsampling algorithm**

(57) The video memory requisite of an MPEG decoder effecting a decompression of the I, P and optionally also of the B picture according to the MPEG compression algorithm and requiring the storing in respective buffers organized in said video memory of the respective MPEG- decompressed data, may be dynamically reduced by subsampling and recompress-

ing according to a ADPCM algorithm at least the data pertaining to the I and P pictures before coding and storing them in the respective buffers. Subsequently, the stored data are decoded, decompressed and upsampled for reconstructing blocks of pels to be sent to a macroblock-to-raster scan conversion circuit.



EP 0 817 498 A1

PAL	720x576x8 for the luma (luminance) (Y)	3.317.760 bits	= 4.976.640 bits
	360x288x8 for the U chroma (chrominance U)	829.440 bits	
	360x288x8 for the V chroma (chrominance V)	829.440 bits	
NTSC	720x480x8 for the luma (luminance) (Y)	2.764.800 bits	= 4.147.200 bits
	360x240x8 for the U chroma (chrominance U)	691.200 bits	
	360x240x8 for the V chroma (chrominance V)	691.200 bits	

Therefore, in a PAL system, which representing the most burdensome case, may serve as a reference example, the actual total amount of memory required will be given by:

$$1.835.008 + 835.584 + 4.976.640 + 4.976.640 + (4.976.640 \cdot 0.7407) = 16.310.070 \text{ bits.}$$

This calculation considers a 0.7407 optimization of the B-picture frame buffer.

A further optimization may consist in undertaking the decompression of the B-picture without resorting to a storage step in the external RAM by carrying out an equivalent function internally in the integrated decoder device by a dedicated circuit block functionally placed upstream of the Display Unit.

Considering this further optimization, the video RAM requirement drops to:

$$1.835.008 + 835.584 + 4.976.640 + 4.976.640 = 12.623.872 \text{ bits.}$$

Where the B-buffer is realized within the same chip containing the "core" of the decoder being required to convert the scanning of each 8\*8 block, defined in the MPEG-2 compressed data stream, in that of each row of the picture (field or frame) required by the video display process of the picture itself. Such conversion macrocell is commonly called "MACROBLOCK TO RASTER SCAN CONVERTER".

In the prior European patent application No 96830106.9, filed on 11 March 1996, in the name of the same applicant, date that is herein claimed as a priority date for the common disclosure, a method and relative device were described that allowed for a remarkable reduction of the above cited video memory requisite to about 8Mbits.

The idea behind the invention that was described and claimed in the above identified previous patent application, is the recognition that the amount of memory required by the MPEG decoding process as stated in the above calculations, can be remarkably reduced when allowing for a recompression of the pictures used as a reference for the prediction (I-picture and P-picture for the case of the standards MPEG-1 and MPEG-2), after the MPEG decompression and before they are temporarily stored in the external video memory and their decompression when they are read from the external memory.

It has now been discovered and represents the object of this new patent application that, the video memory requisite may be synergically minimized, reducing it in practice to only 4Mbits, by carrying out a data subsampling, prior to the ADPCM recompression used to reduce to 8Mbits the memory requisite, of at least the I and P images after MPEG decompression and before coding and storing these data in the respective video memory buffers. Subsequently the decoded data, decompressed by blocks of pals during the reconstruction phase and before being sent to a "MACROBLOCK TO RASTER SCAN" conversion unit, are upsampled congruently to the subsampling factor used before their recompression.

It has been found that the degrading of the picture quality (picture definition) following to this subsampling operation and subsequent data upsampling, remains approximately within limits that are hardly noticed when the picture is displayed on a T.V. screen.

Furthermore, the "core" architecture of the data processor, according to the present invention, allows for a simplified implementation of proper means that select a mode of full reduction of the video memory requisite by carrying into effect such subsampling and upsampling operations, or disable this optional mode of minimization of the memory requisite retaining a higher picture quality with a video memory requisite of 8Mbits, which remains by far lower than the memory requisite of prior known systems.

Basically, this invention permits the implementation of an "adaptive" system for automatically managing video memory resources in order to optimize the performance of the device "core" in function of the operating conditions and accordingly of the prevailing memory requisites.

In practice, the ADPCM recompression factor may be varied in such a way of optimizing the space available within the external video memory.

If the memory space is enough to the purpose, the memory requisite reduction macrocell, object of the present invention, is bypassed, preserving the full quality of the picture as produced by the MPEG decoder system.

In case of insufficient memory, the system implements the reduction to the 8Mbit memory requisite algorithm described in the preceding application No. 96830106.9 for recompressing at least the I and P pictures. Therefore,

able length decoding block, comprising a "run-length" type decoding stage, a circuit undertaking an inverse quantization function, a processing circuit of the inverse discrete cosine transform (I\_DCT) and a predictor value generation network, and is characterized by further comprising:

- 5 - a buffer for data macroblocks;
- a quincunx subsampling circuit;
- a circuit for coding and recompressing, according to an adaptive differential pulse coding modulation (ADPCM) scheme, that decompresses the I and P pictures, encoding the I\_DCT block output data that, after motion compensation, are written in the respective buffers by the external memory;
- 10 - a circuit for decompressing and decoding the output (ADPCM) data from the I\_DCT block relative to the I and P pictures so recompressed, read from the respective buffers of the external memory, capable of generating a video data stream relative to the I and P pictures, together with the outcoming data from the I\_DCT relative to the decompressed B-pictures;
- a buffer for such video data stream; and
- 15 - an upsampling circuit of said video data stream.

According to an embodiment of the invention, the coding and recompressing circuit may comprise:

- an acquisition buffer of the decompressed I-DCT data produced by the MPEG decompression block;
- 20 - a circuit that assesses the energy content of the buffer and generates a digital variance value of the pel values of the different data blocks output from the I\_DCT block to be stored in the respective buffer of the external memory;
- a multilevel quantizer, coherently conditioned by the actual or current digital variance value generated by said circuit;
- a differentiator capable of receiving through a first input the I-DCT data stream produced by the MPEG decompression block and, through a second input, a predictor value and of producing an output data stream to be sent to the input of said quantizer;
- 25 - a coding and write circuit of the recompressed data in the respective buffers of the external memory capable of receiving as input the output stream of the quantizer;
- a network for the generation of said predictor value comprising a multiplexer capable of receiving through a first input the I\_DCT input data stream and through a second input the predictor value generated by the network;
- 30 - an adder capable of receiving through a first input the output stream of the quantizer, through a second input the data output by said multiplexer and of producing an output stream of sum data;
- a limiter circuit capable of receiving as an input said sum data stream produced by said adder and followed in cascade by a circuit that generates said predictor value which is supplied to the second input of the differentiator stage and of the multiplexer.
- 35

The decompressing and decoding circuit can be constituted by a decoding circuit capable of receiving through a first input a compressed and coded data stream coming from the respective external memory buffers and through a second input the relative variance value previously stored in the same external memory buffers and by a decompression network made up of an adder summation stage capable of receiving through a first input the decoded data stream output by said decoding circuit and through a second input the predictor value relative to the decompressed pel value, already generated at the output of the adder, followed by a limiter of the pixel values.

Of course, the dimensions in pels of the luminance and chrominance blocks of data, the format of the I-DCT data according to the MPEG compression scheme, the format of the recompression data of the already decompressed I and P pictures according to the ADPCM scheme, as contemplated by the invention, as well as the format of the estimated digital variance value and the number of levels of the relative quantizer can be different from those indicated by way of example in the present description and will normally be defined based on design preferences of the video decoder or receiver.

The various aspects and relative advantages of the invention will be even more evident through the following description of an important embodiment and by referring to the attached drawings, wherein:

**Figure 1** is a block diagram of the "core" of a video decoder according to the present invention;

**Figure 2** shows a detail of the MR Encoder/Decoder of the general scheme of Fig. 1;

**Figure 3** is a scheme of the bufferization scheme, subsampling, recompression and ADPCM coding;

**Figure 4** shows a possible scheme of the quincunx subsampling block;

video memory is optimized by taking into account the need of storing words of several bits less than 16 which is the usual number into which is organized the external video memory. This opportunity of optimizing is no longer needed when the system enables a reduction of the full memory requisite to about 4Mbits by enabling the subsampling algorithm before the ADPCM recompression.

5 In the preferred case of a "direct" reconstruction of the B-pictures this is then realized as follows:

- the ADPCM compressed I and P predictors are read from the external DRAM memory and ADPCM decompressed in order to perform motion compensation of the B-picture that is currently being MPEG decompressed by the "pipeline", and subjected to a median subsampling procedure.

10

The macroblocks of I-DCT data so reconstructed are sent to the conversion circuit "MACROBLOCK TO RASTER SCAN", upstream of the display Unit of the diagram shown in Fig. 1 and they are then displayed.

This procedure does not require any buffer in the external memory destined to store the B-picture because such a buffer is present in the macrocell "MACROBLOCK TO RASTER SCAN CONVERTER B-PICTURE".

15

In line with a fundamental aspect of the system of this invention characterized by its adaptability to changing conditions of video memory availability (for example by supposing of having available a 16Mbits external memory), the system is perfectly able of deactivating the algorithm that reduces the memory requisite through ADPCM recompression, coding and eventual writing in the video memory or otherwise to activate it.

This operation is implemented by controlling two multiplexers through the microprocessor.

20

The enabling/disabling scheme of the function that reduces the memory requisite in an adaptive manner through the controlling microprocessor, is illustrated in Fig. 2. In this partial view are shown in detail the two multiplexers controlled by the microprocessor that perform the activation or deactivation of the ADPCM recompression system through the MR Encoder and MR Decoder blocks.

25

The detailed view of the MR Encoder/Decoder block of Fig. 1 also shows an Embedded MR Memory for the optimization of the external memory management, in line with the cited previous European Patent application.

A feature of the bufferization, "quincunx" subsampling and recompression block of Fig. 1 relative to the data output by the I-DCT block (for the sake of brevity called I-DCT data) pertaining to the decompressed I and P pictures, is shown in Fig. 3.

30

The diagram of Fig. 3 also includes two multiplexers MUX to automatically actuate the selection between a reduction of the memory to only 4Mbits through a data subsampling before ADPCM recompression or to 8Mbits through ADPCM recompression alone, in practice by disabling the subsampling algorithm.

The quincunx subsampling realized within the homologous block, may take place by discarding one every two pixels belonging to each luminance data of a video line (row) to be written in the RAM. The process is repeated line by line thus "offsetting" the position of a pixel.

35

As diagrammatically shown in Fig. 4, the quincunx subsampling may be simply realized by directing the pixels stream through an array of D-flip/flops, functioning in parallel, driven by a half-frequency clock if compared to the frequency of the pixels stream. This half-frequency clock may be selected by a multiplexer MUX, at the input of which are applied the complementary clock signals of F/2 frequency if compared to the basic frequency F of the pixels stream through the flip-flop bank. The signal of line parity commands the clock selection thus producing a quincunx subsampling grid.

40

The quincunx subsampling technique assumes that upstream of the subsampling stage in relation to the digital data stream, a frequency reduction of the band of the video signal to comply with the subsampling algorithm. In case that the subsampling reduces to a half the effective number of samples of the data of a videoline, the band will also need to be reduced to a half. Such a necessary filtering is performed by the Antialiasing Filter whose functional scheme is given in Fig. 5. The filtering is performed by generating the sum of the products between appropriate coefficients and adjacent pixels. The T registers may be D-flip/flops that store these adjacent pixels for the time necessary to the filter to output the filtered pixel. These adjoining pixels are multiplied by preestablished coefficients and added in order to produce the output datum.

45

By referring to Fig. 7, the ADPCM encoder block comprises a 64\*8 bit buffer (block buffer) for the acquisition of the I-DCT input data. A dedicated circuit (Variance Estimator) calculates the average pels value of each block of the I-DCT input data and the average of the sum of the absolute values of the differences between each pel of the I-DCT data block. With such parameters it is possible to assess the variance of the input data (pels) block.

50

Figures 8 and 9 show a detailed functional scheme of the variance prediction block according to a preferred embodiment. The detailed scheme of Figures 8 and 9 of the variance predictor block makes use of a standard terminology of immediate understanding by a person skilled in the art. A further definition and description of each of the stages that constitute the circuitual block of the variance estimation is not considered necessary for a total comprehension of the architecture of the present invention.

55

The ROM (Read Only Memory) block may be composed by 56 rows being each of 8 columns (8 bit) as indicated in

The ADPCM compression method is applied to each block into which the picture is decomposed through the following operations:

- Selecting and coding an appropriate quantizer in the digital stream.
- 5 - Coding of the first pixel of the block.
- Decorrelating, quantizing and coding of all the remaining pixels of the block.

The various steps and the circuit architecture that carry out these operations are hereinbelow singularly described:

#### 10 1) Selection and coding of the quantizer.

It is well documented that the distortion introduced by the process of quantization may be reduced if the set of quantization values  $Q(k)$  is calculated by taking into account the energy of the signal to be quantized. It is also known that different portions of a digital picture may present very different energy values. The present method defines the whole of the values  $Q(k)$  relative to each block as a function of the energy of the block itself as follows:

- \* The whole of the values  $Q1(k)$ ,  $k=1, \dots, L$  utilized in the case of unitary energy are known both to the coder and to the decoder;
- \* The  $U$  energy of the block is estimated and coded in the digital stream;
- 20 \* The values  $Q(k)$  effectively used by the block are calculated as:  

$$Q(k) = Q1(k) \cdot U; k = 1, \dots, L$$

An estimation of the block energy may be made in a relatively simple way by hypothesizing a Laplacian statistic of the prediction error. Indeed, in this case the energy may be calculated by multiplying by the square root of two the mean of the absolute values of the block prediction errors. The coding of the energy may be simply done by scaling in terms of the maximum value and by representing the result on a  $K$  number of bits, so to basically realize a uniform quantization. In selecting the quantizer of the prediction errors it is also necessary to take into consideration the peak value of the errors of quantization, because in the case of large prediction errors it might occur that the peak restitution value of the quantizer, according to the scheme shown hereinbelow, be too small. Thus, simultaneously to the calculation of the variance, the peak values of the prediction for the first column error are also calculated, within which, large prediction errors are likely to occur because of the greater distance among the lines of a field during the interlaced scanning, and for each group of  $G$  consecutive horizontal lines (i.e.  $G=2$ ). A bit is added to the coding of each of these groups of pixels in order to signal the event of an excessive peak of prediction error, and as a result of it, the choice of a quantizer that corresponds to a  $2 \cdot U$  energy in the case of a pair of rows and to  $4 \cdot U$  in the case of the first column.

35 A circuit architecture as that illustrated in details in Figures 8 and 9 may be used for calculating this variance estimation.

#### 2) Coding of the first pixel of the block

40 By referring to the scheme of Fig. 7, the first pixel of the block, previously indicated as  $P(1, 1)$ , is not subject to any sort of prediction, thus it is coded according to its original resolution by way of  $B$  bits.

#### 3) Decorrelation, quantization and coding of all the other pixels of the block

45 By referring to the scheme of Fig. 7, for each pixel of the block, the pixel  $P'$  as previously defined will be adopted as the predictor. It should be noticed that this predictor, according to the scanning order, has already been quantized and reconstructed, and therefore is not taken from the original picture. This permits a better control of the picture's quality, coherently with known ADPCM techniques.

Fig. 7 shows a circuit where, besides giving a general view of the encoder, also provides details of the prediction and quantization loop of single pixels. The calculation of the prediction error is carried out in terms of modulus and sign. This permits to simplify the quantization, by halving the number of levels upon which the quantization operates. Indeed, it is known that the statistics of the prediction error is symmetric about the zero.

Figures 10 and 11 illustrate a circuit embodiment of the quantizer.

55 The scheme of Fig. 10 shows the architecture used for generating the seven threshold values  $S0, S1, S2, S3, S4, S5$  and  $S6$  that represent the arithmetic mean of the restitution values  $T0, \dots, T7$ . In particular, the mean is calculated among adjacent restitution values (i.e.  $S2 = T2 + T3$ ) and this result is not divided by two to maintain full accuracy. Of course this is compensated by multiplying by two the "err" value of the scheme of Fig. 11 that is in fact represented with 9 bits (i.e. 1 sign bit is added) rather than with 8 bits.

$$(2 * 16 * 8 * 8) + (2 * 8 * 8 * 8) = 3.072 \text{ bits}$$

luma chroma

**In each PAL picture there are 1.620 macroblocks:**

$$3.072 \cdot 1.620 = 4976640 \text{ bits}$$

It is known that the chrominance signal has a lower content of information, presenting a band restricted to the lowest spatial frequencies. This implies a greater predictability of the chrominances themselves, that is, a greater efficiency of the ADPCM compression. By considering a 3 bit/pixel compression for the luminance and a 2 bit/pixel for the chrominance we would then obtain:

$$(2 * 208) + (144 * 2) = 704 \text{ bits}$$

luma      chroma

Therefore, each frame occupies:

$$704 \cdot 1,620 = 1,140,480 \text{ bits}$$

The macroblock compression factor so obtained is equal to 4.36.

### EXAMPLE OF APPLICATION TO AN MPEG DECODER

By taking into account the above relationships it is possible to reach the target for a reduction to 4 Mbits of the video memory register by assuming such compression of the MPEG decompressed I and P pictures.

This result is attained by first quincunx subsampling and then ADPCM recompressing the I and P pictures after MPEG decompression and before they are stored in the external memory. They will be then decompressed when read from the external memory as shown in Fig. 1.

The compression is applicable to an 16\*8 block output from the I-DCT and from motion compensation, according to an adaptive DPCM scheme. In particular, in the considered example, for the 16\*8 blocks of luminance a 3 bits compression is selected, whereas for the 8\*8 blocks of chrominance a 2 bits compression is selected.

Thus, for the PAL format case the memory requisite is as follows:

$$1.835008 + 835.584 + 1.140.480 + 1.140.480 = 4.951.552 \text{ bits } (=4.722\text{Mbits})$$

```

|
| compressed and subsampled P buffer
I compressed and subsampled I buffer

```

For a NTSC format the requisite would then be of 4.571.392 bits.

An illustration of the processes of subsampling/upsampling and ADPCM compression/decompression is illustrated in Figures 14 to 16.

The MPEG decompressed digital image following to the inverse cosine discrete transform is in macroblock format, constituted by 16\*16 pels for the luminance component and by two 8\*8 pels for each luminance component U and V.

These blocks, as shown by the block diagram of Fig. 3, are bufferized and broken down into two blocks of 16x16 pels for the case of the luminance component.

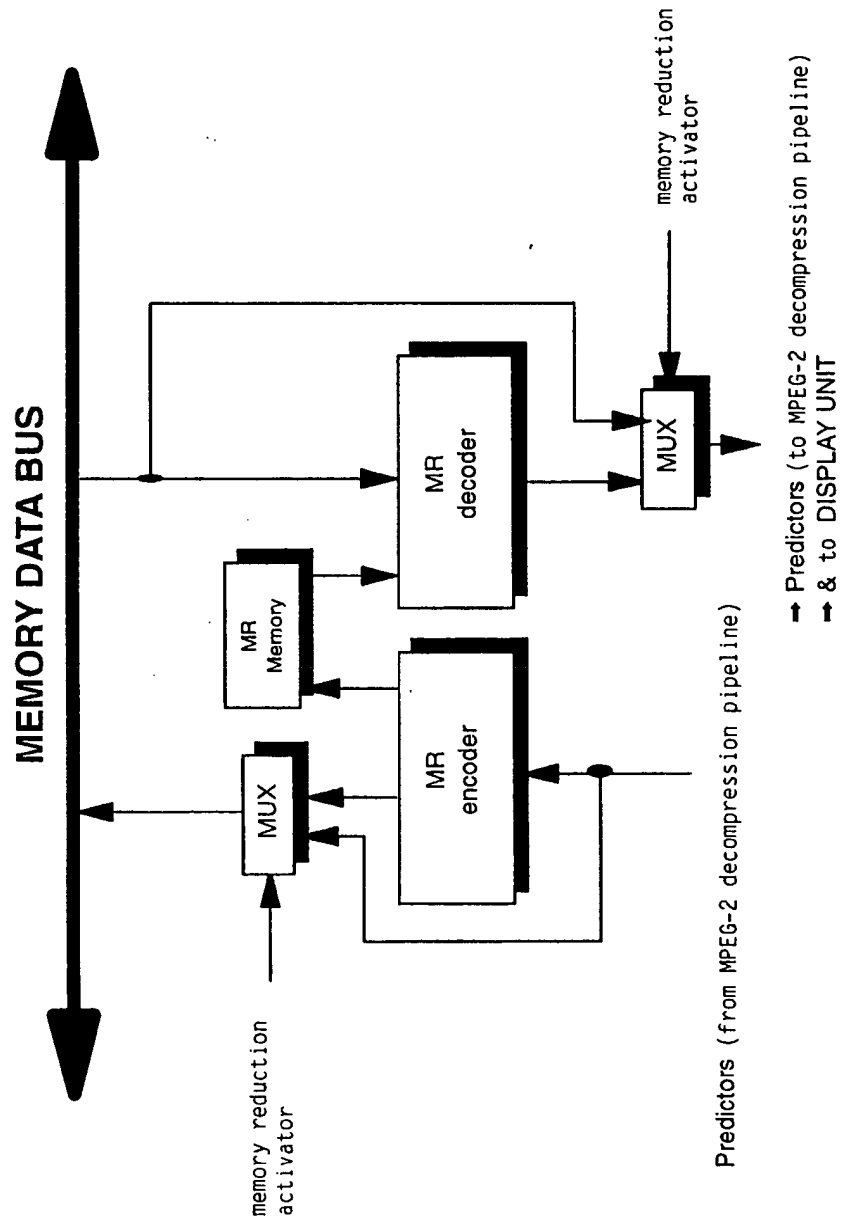
Each of these (for the luminance alone) is subsampled according to a grid commonly referred to as quincunx, as shown in Fig. 14.

A new block of 8\*8 pels is so obtained. This block feeds the ADPCM Encoder block of Fig. 3, according to the scanning path shown in Fig. 14 by the dashed line.

Thereafter the ADPCM compression take place as already described above.

- ing to an adaptive pulse code modulation scheme (ADPCM);
- storing the data relative to the I and P pictures in the form of subsampled and recompressed blocks so coded in the respective buffers of the video memory;
- 5 decoding the stored data relative to subsampled and recompressed blocks of pels relative to said I and P pictures;
- 10 decompressing said data relative to said blocks of pels according to said adaptive differential pulse code modulation scheme (ADPCM)
- upsampling said decoded and decompressed data by reconstructing blocks of pels sending them to the conversion circuit macroblock to raster scan.
- 15 2. The method according to claim 1, characterized in that the amount of video memory requisite reduction is modifiable by enabling said ADPCM recompression algorithm and coding before the writing of data in said video memory and of decoding and ADPCM decompression of the same data read from the video memory to realize a first reduction of the video memory requisite and enabling said data subsampling algorithm before said ADPCM recompression and said median upsampling of the ADPCM decompressed data to implement a maximum reduction of the memory requisite.
- 20 3. MPEG video decoder, interfacing with a control bus and a data processing bus of the video pictures to be written and read in respective buffers external to the "core" of the video decoder which comprises a first "first-in-first-out" (FIFO) buffer for data acquisition and writing of the compressed data in a first bit buffer of an external DRAM memory, a Start Code Detector circuit synchronized by a controller (controller), a bidirectional buffer (I/O unit) for on screen display data (OSD), a variable length decoder (VLD) of the compressed data input stream (bitstream), an MPEG decompression block (pipeline-RLD, I\_QUANT I\_DCT, Predictor Construction) of the data decoded by said variable length decoder, comprising a "run length" decoder, an inverse quantizer circuit, an inverse discrete cosine transform processor, a "predictor" generating circuit, a "MACROBLOCK SCAN TO RASTER SCAN" conversion circuit for a current B-picture upstream of a display unit, characterized in that further comprises
- 25 a bufferization and quincunx subsampling circuit of the data output by said inverse cosine transform processor;
- 35 a coding and recompression according to an adaptive differential pulse code modulation scheme circuit (MR encoder), that recompresses the data relative to at least the I and P pictures of the MPEG algorithm and codes the recompressed data to be stored in the respective buffers of said memory;
- a decoding and decompressing circuit (MR decoder) of said data relative to said I and P pictures read from the respective buffers of said memory and generating a stream of decoded and decompressed data relative to the I and P pictures;
- 40 a bufferization and median upsampling circuit of said decoded and decompressed data stream;
- 45 first multiplexing means enabling/disabling said circuits of bufferization and quincunx upsampling and of said bufferization and median upsampling;
- second multiplexing means enabling/disabling said ADPCM recompressing, coding, decoding and ADPCM decompressing circuits;
- 50 means capable of implementing the selections of said enabling/disabling states of said multiplexer via command signals sent through said control bus.
- 55

# MEMORY REDUCTION BLOCK DIAGRAM



**FIG. 2**

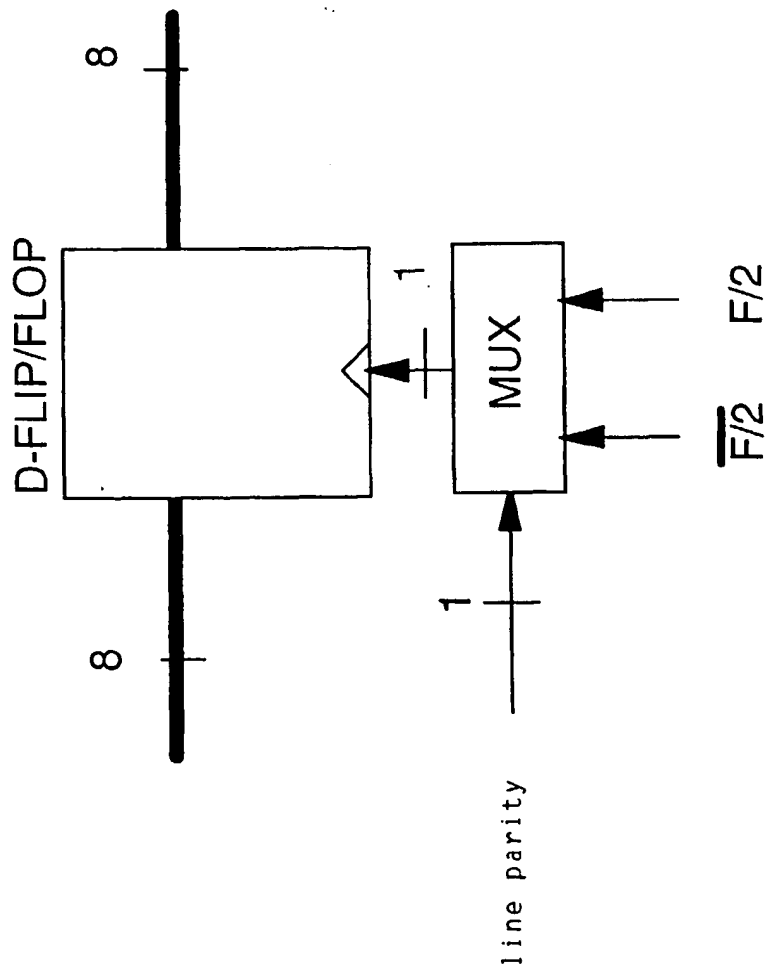


FIG. 4

## DECODER

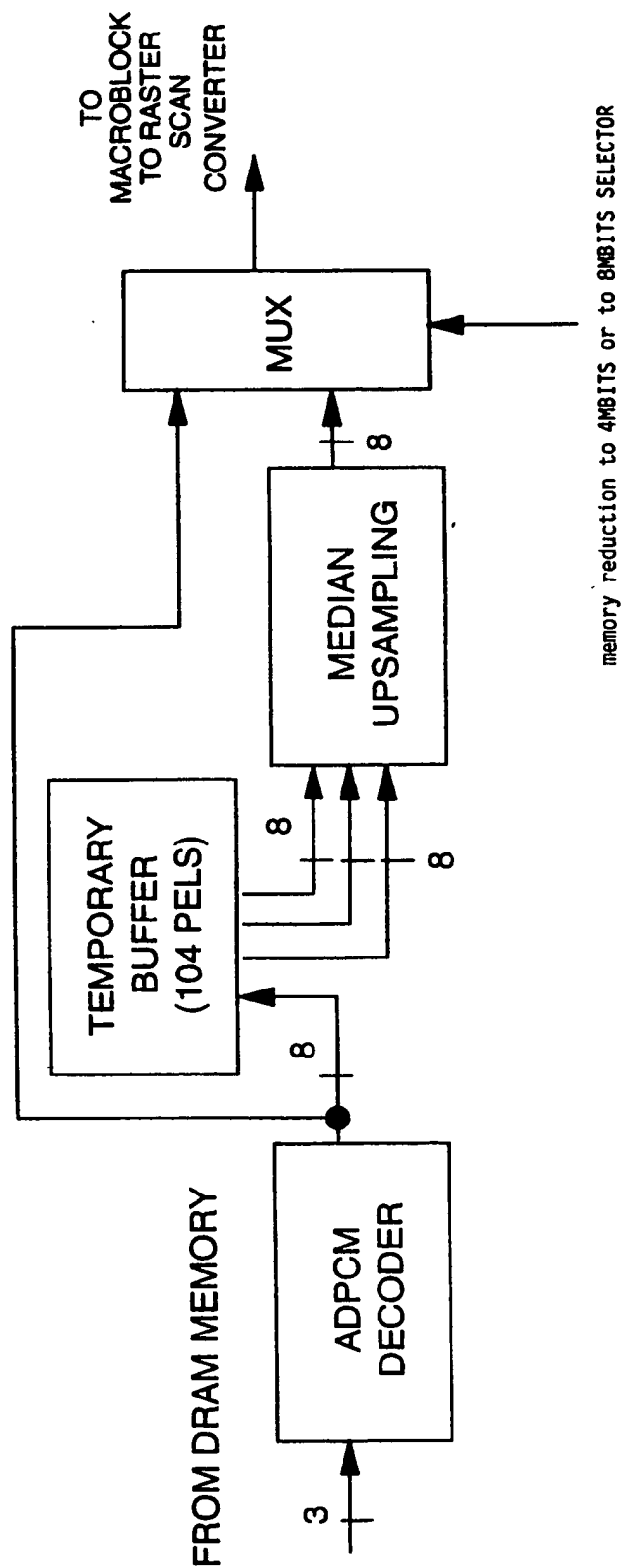
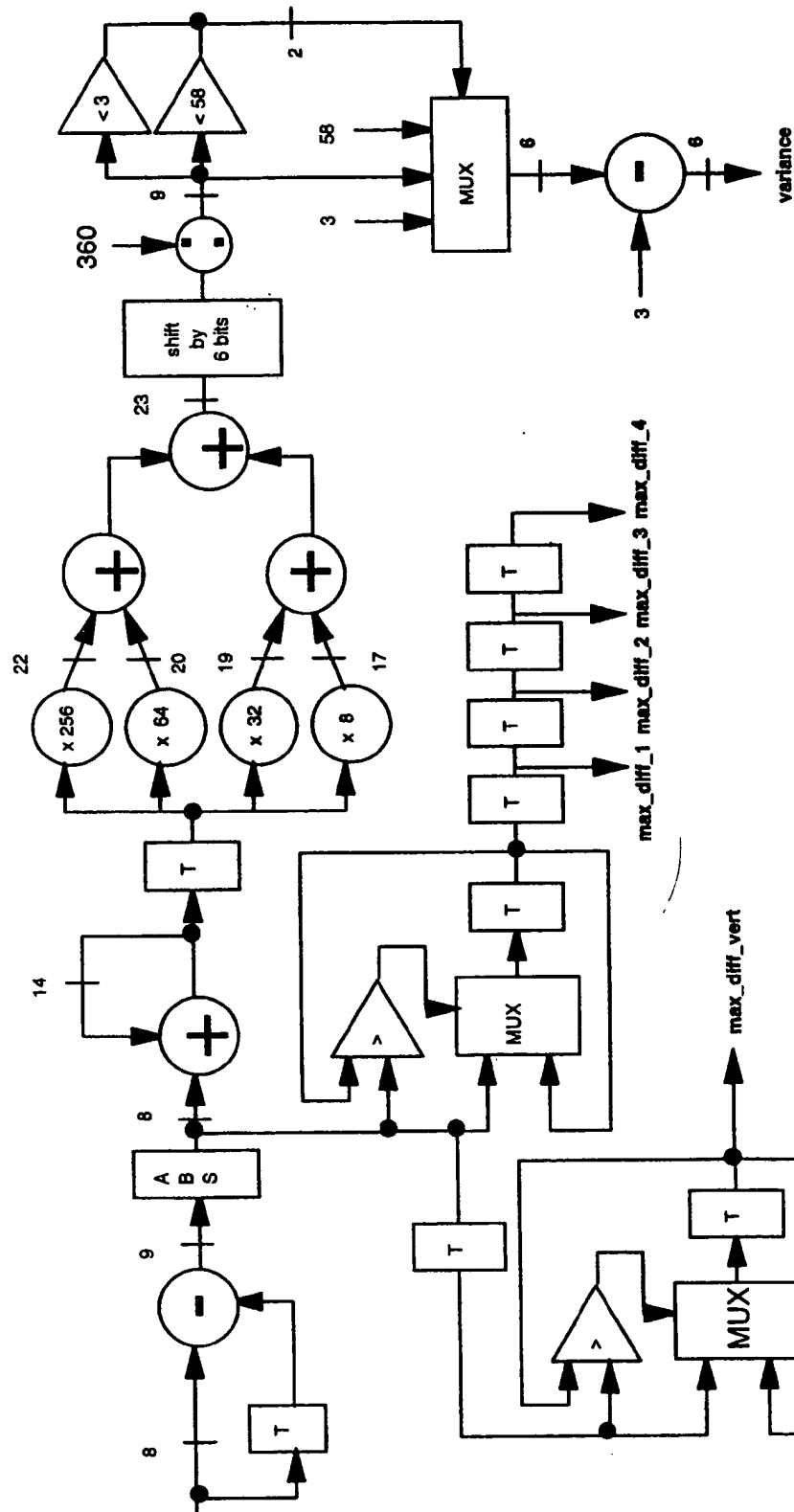


FIG. 6

# VARIANCE ESTIMATOR (1)



**FIG. 8**

# THRESHOLD GENERATION

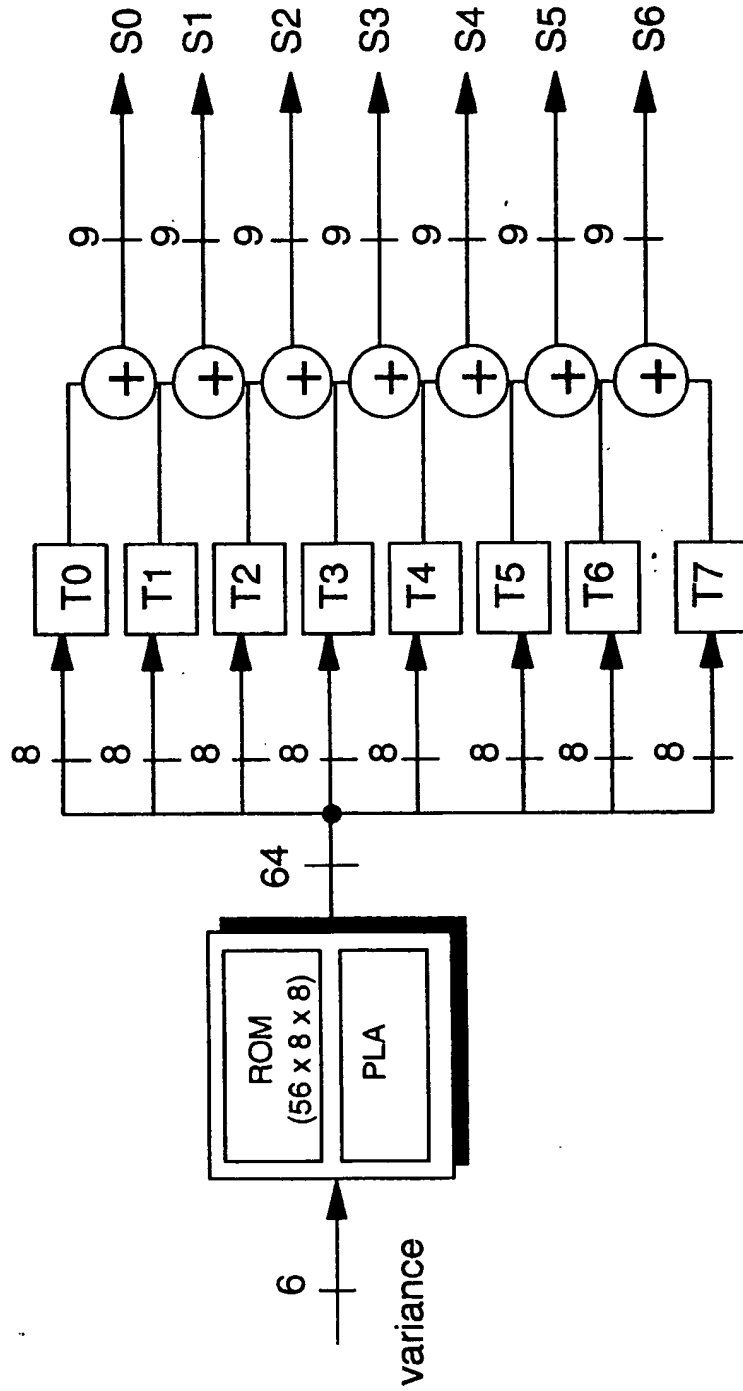


FIG. 10

# ADPCM DECODER

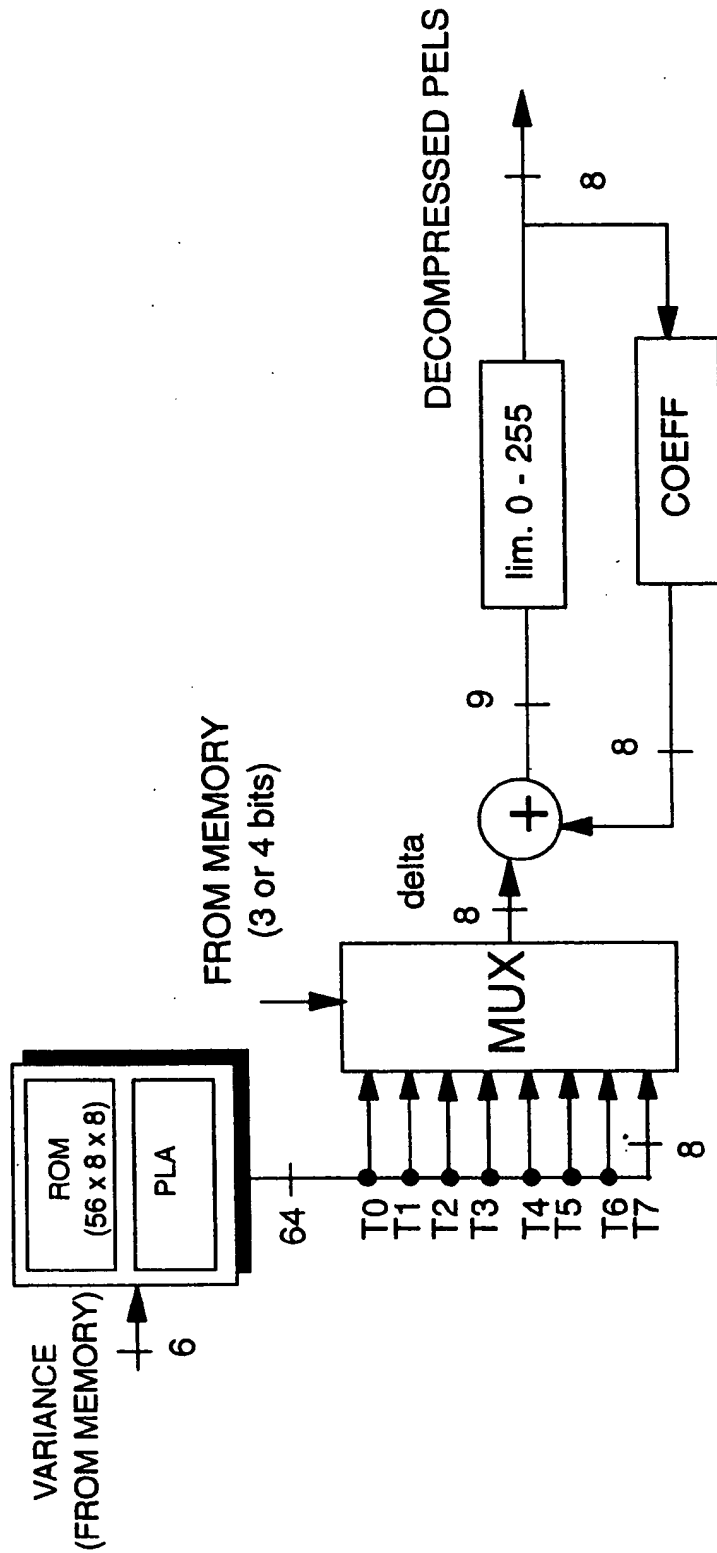
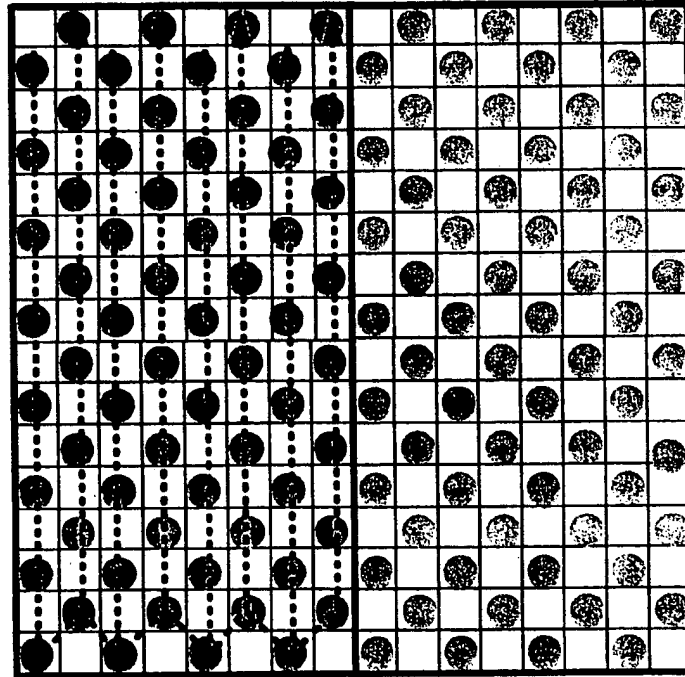


FIG. 12

# LUMINANCE SUBSAMPLING AND CO/DECOMPRESSION



□ PELS OF 16\*16 MACROBLOCK

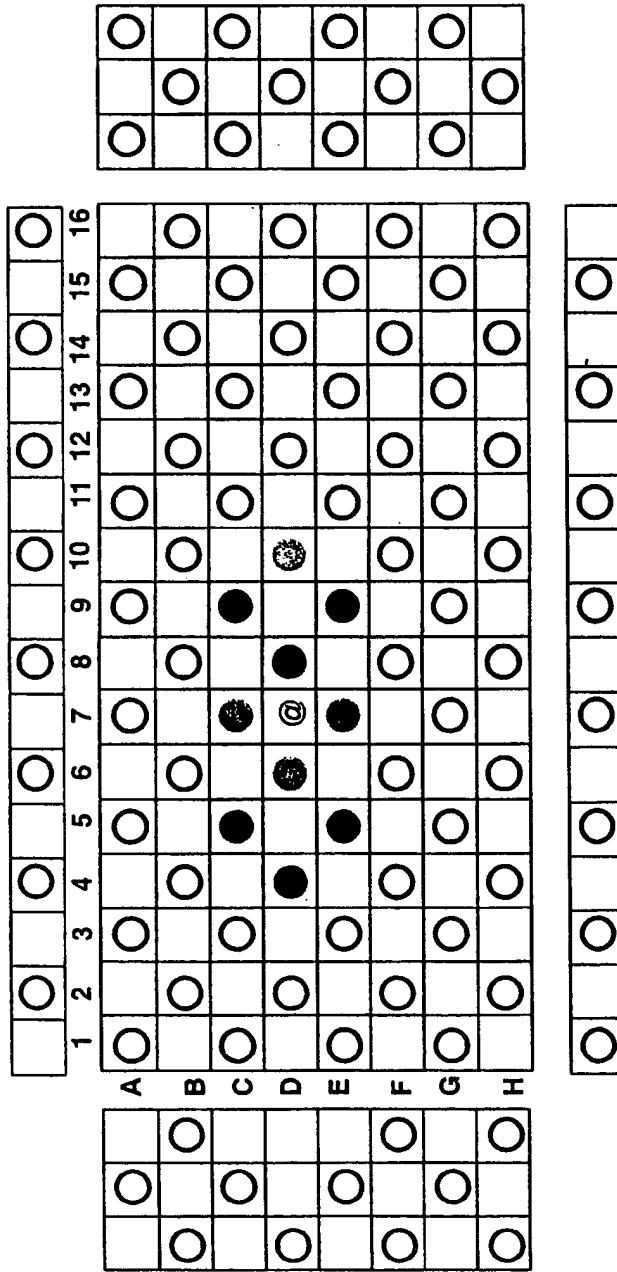
● UPPER PELS CO/DECOMPRESSED  
(8\*8 PSEUDO BLOCK)

● LOWER PELS CO/DECOMPRESSED  
(8\*8 PSEUDO BLOCK)

..... SUBSAMPLED BLOCK SCAN PATTERN

FIG. 14

# UPSAMPLED WINDOW



D5 = median (D4, C5, E5)

D7 = median (D6, C7, E7)

D9 = median (D8, C9, E9)

$$@ = c0*D4 + c1*D5 + c2*D6 + c3*D7 + c4*D8 + c5*D9 + c6*D10$$

FIG. 16